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TOWARD ENTERPRISE PROCESS ENGINEERING: CONFIGURATION MEASUREMENT AND ANALYSIS

by

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Over the past two decades, the enterprise process[1] has become a central unit of analysis in management. For instance, as the focus of analysis through Total Quality Management in the Eighties [9, 11, 12], the process is used to understand and improve the cross-functional flow of work through an enterprise. The process continues to represent the central unit of analysis through Business Process Reengineering in the Nineties [1, 8, 10, 14], for it is stressed as fundamental to design at the enterprise level.

With this process focus has come increased management attention to its cross-functional measurement. For instance, methods such as activity-based costing [4, 6, 21] seek to allocate costs, across functional departments and organizations, to enterprise activities in a manner that reflects their contribution to the specific products, services or other outputs of each process. The problem is, the majority of measures proposed and employed for process measurement focus only on performance, which represents an output measure.

Output measures have been shown to be quite useful as indicators of how well an enterprise is performing (e.g., signaling problems in a particular product line or organization, measuring return on investment). However, they have limited use in diagnosing the root causes of problems that occur. And they offer negligible support for predicting future process performance in advance of implementing a particular enterprise design.

The relative absence of process-diagnostic and -predictive capability available to the enterprise manager provides a contrast with powerful and proven theories, methods and tools from Operations Research (e.g., optimization), Industrial Engineering (e.g., time studies) and other management disciplines (e.g., information systems analysis and design). But despite serious research applying management science techniques to address the enterprise-design problem (e.g., [5]), our traditional approaches have not had the same magnitude of impact on enterprise process design as they have solving intra-functional problems (e.g., manufacturing scheduling, logistical routing, service queuing).

[1] When discussing the process unit of analysis in this paper, we use the more general term *enterprise*—as opposed to *business*, *company* or *firm*. This is to suggest the associated design and management activities discussed here are just as applicable to the government agency, military command, non-profit group, virtual organization and other modern managerial entity addressed through management science.

This dearth of management theory and design impact also provides a contrast with the rich models and tools produced through research in the physical sciences. Most engineering disciplines (e.g., aerospace, civil, electrical) are supported by theory-based models and quantitative analytical tools that enable problem diagnosis and performance prediction for alternative designs. Critical to such models and tools is the ability to measure and make predictions from the configuration of a design artifact. With the proposition that enterprise process design represents an engineering problem as much as a managerial one, the concept of configuration may offer promise in overcoming design limitations that currently confront the enterprise manager.

Configuration Approach

As a predominantly engineering term, *configuration* denotes a measurable model or representation of a design artifact. Many examples of configuration-based design and analysis for performance prediction can be drawn from various engineering disciplines. The aerospace engineer analyzes configuration measurements (e.g., thrust and weight) of alternative air vehicle designs to predict their behavior and performance in flight (e.g., using aerodynamic models). The civil engineer analyzes configuration measurements (e.g., span and depth) of alternative bridge designs to predict their behavior and performance under loads (e.g., using vibration models). The electrical engineer analyzes configuration measurements (e.g., voltage and impedance) of alternative device designs to predict their behavior and performance when connected to power sources (e.g., using circuit models), and so on.

At present, our level of understanding in management science lacks corresponding concepts and techniques for configuration measurement and analysis to predict the behavior and performance of alternative enterprise processes. Indeed, researchers working at the current state of the art in this area continue to address the representation problem, but they have yet to effectively incorporate the key capabilities of measurement and performance prediction noted above.

For instance, in work toward developing a handbook of organizational processes, Malone et al. [16, p. 426] state, "the key theoretical challenge is to develop techniques for representing processes." This work summarizes the current state of the art in terms of techniques for process representation and comparison. But despite the rich formalism and tool developed for this purpose, the associated process-handbook approach does not support the kind of measurement-based analysis and performance prediction found in well-established engineering disciplines.

As another instance, in work toward enhancing model management, researchers [2] draw from Graph Theory and employ the metagraph to overcome many information system design limitations associated with model integration. This work summarizes the current state of the art in terms of techniques for model design and management. But despite the graph-based formalism and insight developed for this purpose, the associated metagraph approach does not address the enterprise process, and the extant work does not consider measurement or performance prediction.

Other researchers [17] complement the work above through a graph-based approach to enterprise process representation, which they couple with inferential techniques such as heuristic classification [13] to diagnose process problems and shortcomings. This work summarizes the current state of the art in terms of techniques for automated process diagnosis. But despite the configuration-based formalism and tool developed for this purpose, the associated diagnostic approach does not address process measurement.

In this paper, we build upon and integrate the seminal works above (e.g., [2, 16, 17]) through the use of a graph-based formalism to represent enterprise processes (see [20]). But the research described here extends this prior work to adapt the well-established engineering concept of configuration to enable quantitative measurement and analysis of enterprise processes. With a theoretically sound and robust scheme for configuration measurement—as well as representation—management science may be able to take an important step forward toward informing and supporting enterprise process design, particularly through the ability to predict process performance in advance of implementation. This represents a principal objective and contribution of the present research.

The organization of the paper follows this introductory section with background pertaining to engineering configuration measurement and analysis. The discussion then turns to graph-based configuration constructs and measures developed specifically for the enterprise process. Drawing from Graph Theory and Measurement Theory, the paper integrates this work and demonstrates useful analytical properties associated with the kinds of measures proposed. The discussion closes with conclusions and implications in terms of management science and continued research along the lines of this investigation.

CONFIGURATION-BASED ENGINEERING DESIGN

In most well established engineering disciplines, the configuration of a design artifact represents its physical composition, including systems, subsystems, components and relations between them. As such, configuration is a descriptive tool employed by engineers to represent a particular design. And each design alternative contemplated and analyzed by an engineer is represented through a distinct configuration.

Figure 1 illustrates the approach in the aerospace domain, as the aircraft system depicted can be described in terms of a configuration. For instance, it has a single wing pair, twin jet engines, two vertical stabilizers, fly-by-wire (FBW) flight control system, aluminum airframe, plastic canopy and other subsystems and components that are used to represent this design. And the configuration used to represent this aircraft design—which depicts a vehicle designed for a fighter mission—is quite different from that of an alternative design for a cargo aircraft or manned bomber. For instance, cargo and bomber aircraft—designed to perform different missions than the fighter—are generally much larger than their fighter counterparts and designed to carry heavy loads across long distances, whereas speed and maneuverability are stressed in fighter designs. Thus, the configuration of an engineered artifact reflects purposeful design and can be used to differentiate between different design classes and instances.

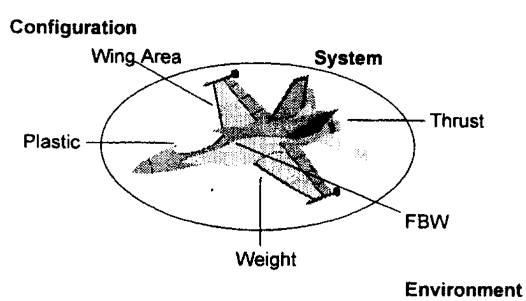

Figure 1 Air Vehicle Configuration

An important capability associated with the configuration used to represent a design is measurement. As illustrated through the fighter aircraft design depicted in Figure 1, many configuration elements can be measured and used for analysis. For instance, we can weigh the system, measure the area of its wings, assess the propulsive thrust of its engines and so forth for other measurable properties. And measured values obtained from this fighter-aircraft configuration would be quite different from those obtained from cargo, bomber and other classes of aircraft. For instance, larger cargo and bomber aircraft would be expected to weigh much more than a fighter and have much larger wings to support the corresponding weight in flight through lift. With this, differences between alternative classes and instances of aircraft designs can be quantified (e.g., in terms of weight, wing area, thrust), which enhances the designer's ability to describe various engineered artifacts.

But configuration measurements are useful for more than system description. When linked with appropriate theory (e.g., kinematics, aerodynamics) and models (e.g., rigid bodies, airfoils), such measurements also support an analytical capability, through which engineers have the ability to predict the relative performance of alternative designs. For instance, using measurable aspects of the air vehicle configuration depicted in Figure 1, a designer can use the ratio of thrust to weight to predict the aircraft system's maximum speed and altitude. From the theory and models, higher thrust-to-weight ratios are required to overcome forces of drag and gravity, so corresponding fighter designs are expected to fly faster and higher than their cargo and bomber counterparts.

Additionally, when designing such an aircraft, the engineer can employ aerodynamic theory and models in a deductive manner. For instance, the engineer begins with required performance levels and works backward—through theory and models—to determine what parameter values are required for the corresponding configuration to achieve this required performance level. In the case of aircraft speed in this example, the engineer could deduce the thrust-to-weight ratio required to achieve a certain mach number and work to design the configuration accordingly (e.g., using more powerful engines, lighter airframe materials). Through this design process, the engineer has great confidence the resulting aircraft artifact will meet performance requirements, even in advance of the artifact being built. This represents the kind of predictive capability desired for enterprise process design.

PROCESS CONFIGURATION ANALYSIS

In this section, we draw from basic Graph Theory and employ its key concepts to articulate a graph-based approach to representing measurable enterprise process configurations.

Graph Theory Basics

We draw from basic Graph Theory to develop a representational scheme for process configuration that supports measurement. Graph Theory has its basis in the mathematics of Set Theory and Relation Theory. It provides a rich set of concepts and axioms for analysis. Only the basics of Graph Theory, with which the reader is likely to be familiar, are necessary to understand the discussion below. More detailed treatment can be found in a number of textbooks [3, 18].

Briefly, the fundamental elements of Graph Theory are *node* and *edge*. Edges connect nodes in a graph and are used to form networks, trees, forests and other patterns. Where edges are used to depict irreflexive (e.g., directional) relationships between nodes, they are called *directed edges,* and the resulting pattern is referred to as a *directed graph.* We make this concept more precise through the following definition.

Definition 1. A directed graph (or digraph) G consists of a finite set V of vertices or nodes and an irreflexive binary relation E on V. The graph G is denoted as (V, E).

In this definition, the relation is called *adjacency*. It denotes nodes in a graph connected by an edge.

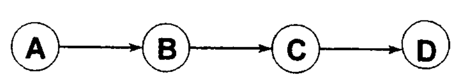

Figure 2 Process Digraph

As an example, the representation presented in Figure 2 is used to depict a process digraph. The figure delineates a simple directed graph with four nodes (A, B, C, D) connected by three edges. Following [16] and [17], the convention is to represent work activities as nodes and use directed edges to delineate the flow of work through the process. Using Definition 1, we can express this graph in set notation as follows.

$V = \{A, B, C, D\}$

and

$$E = \{(A, B), (B, C), (C, D)\}$$

Clearly, the two representations (i.e., of Figure 2 and set notation) are equivalent. For instance, from the adjacency relations, we observe—both graphically and notationally—that directed edges connect nodes A with B, B with C and C with D.

Another important graph-theoretic concept is *path*, which denotes a sequence of nodes and edges. The graph presented in Figure 2 contains one path (A, B, C, D), for instance. In the case of a directed graph, the path denotes direction. We make this concept more precise through the following definition.

Definition 2. Let $G = (V, E)$ be a graph. A sequence of vertices $[v_0, v_1, \ldots, v_m]$ is a path of length m in G from v_0 to v_m if

$$E \ni (v_{i-1}, v_i) \qquad \text{for } i = 1, 2, \ldots, m.$$

Notice this set of relations E implies directionality, as only edges from nodes v_{i-1} to v_i are members of the set. Corresponding relations for the non-directional counterpart of a path, called a *chain*, would also include edges from nodes v_i to v_{i-1} within the set, for example. When representing enterprise processes, in which the flow of work is organized by enterprise design, directed graphs and their corresponding paths are predominant.

One other important graph-theoretic concept is *cycle*, which denotes a circular path. Figure 3 presents an example process representation that includes one cycle. In the case of an enterprise process, cycles are used to represent feedback loops. For example, where a quality control or managerial review activity takes place, work in an enterprise process can sometimes flow back to a previous step (e.g., for rework or revision). The cycle maintains directionality of the graph but allows for such process feedback. We make this concept more precise through the following definition.

Definition 3. A cycle of length m is a path $[v_0, v_1, \ldots, v_{m-1}, v_0]$ from a vertex v_0 to v_0 again.

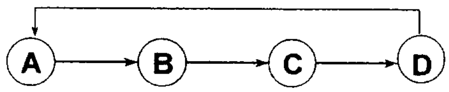

Figure 3 Cyclical Process Digraph

In the process graph presented in Figure 3, the path initiates at vertex A, proceeds through B, C and D as above, and then returns through the top edge from D back to A.

Graph-based Configuration Representation

Here, we adapt the basic graph-theoretic concepts from above to the kinds of enterprise processes targeted for design. For example, Figure 4 presents the same basic graph discussed above through Figure 3, except it also includes several attributes associated with the nodes and edges. Such attributes represent properties of the basic graph elements (e.g., nodes, edges) and are useful for enriching the representation of enterprise processes (see [17]). The richness of graphical representation supported by inclusion of such process attributes facilitates application of graph-theoretic concepts to real-world enterprises.

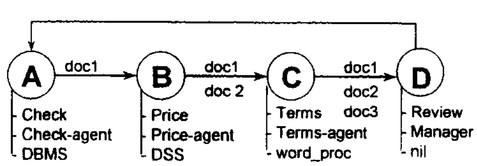

Figure 4 Example Process Representation

In Figure 4, for instance, each activity node is labeled with three attributes to indicate 1) task name (e.g., "Check"), 2) role of the enterprise agent responsible for its performance (e.g., "Check agent"), and 3) tools or equipment employed to automate or support performance of the activity (e.g., "DBMS": database management system). Similarly, each directed edge is annotated with one attribute to indicate the work product flowing through the process (e.g., "doc1": a particular document). This kind of *attributed* directed graph represents a straightforward extension of the basic graph and is supported by many computer-based tools for process representation [7, 17, 19].

The measurement approach begins with counting graph-based constructs used to represent various elements of the enterprise process. For instance, one can employ the concept *node* to operationalize a measurement construct to quantify *process size*. In the example above, nodes are used to represent process activities, so the resulting node count provides a measure to quantify the magnitude or size of a process. A measure such as this can also be used to compare the size or magnitude of a variety of enterprise processes. And similar to the weight measure used in the design of physical artifacts, as a configuration construct, process size may likewise prove useful for predicting enterprise performance. In this example, the size measurement would be 4.

As another instance, one can employ the concept *path* to operationalize a measurement construct to quantify *process length*. Following our size measure from above, one can count the number of nodes in the longest path of a process representation. In the example above, there is only one path through the process, so the resulting node count provides an estimate of the distance or length of the represented process. As above, a measure such as this can also be used to compare the distance or length of a variety of enterprise processes. And this configuration measure may similarly prove useful for predicting enterprise process performance. In this example, the length measurement would be 4. Other dimensions such as process breadth and depth can also be quantified using similar graph-based concepts. And other graph-theoretic concepts, such as *cycle*, can be counted as well (e.g., to measure the number of quality or feedback loops in a process).

As a third instance, one can count attributes used to represent various aspects of a represented process. As examples, one could refer to the edge attribute and count the number of unique documents (e.g., doc2, doc3); this count could then be used to quantify the number of documents created in the represented process (e.g., 3). Similarly, one could refer to the node attributes and count the number of task-names falling into a particular category of interest (e.g., terms, review); this count could then be used to quantify the number of steps with various properties (e.g., number of review or quality-control steps). Other attributes (e.g., agent role, tools/equipment) can be counted and used for process configuration measurement in similar fashion.

Table 1 Graph-Based Process Configuration Measures

Measure	Basis	Process A	PROCESS B
Size	Node count	4	4
Length	Path length	4	3
Breadth	Number of paths	1	2
Reviews	Review attributes	1	1
Manager roles	Role attributes	1	1
IT support	IT attributes	3	3

A sample of graph-based process configuration measures and values is presented in Table 1. The measurements listed under the "Process A" label are obtained from the example representation presented in Figure 4 above. For comparison and contrast, measurements obtained from an alternative process representation, presented in Figure 5, are listed under the "Process B" label. Notice both processes are the same size (4), but Process B is both shorter (length = 3) and broader (breadth = 2) than Process A (length = 4, breadth = 1). Here, we begin to see the kinds of comparisons and contrasts that can be quantified with respect to enterprise process configuration.

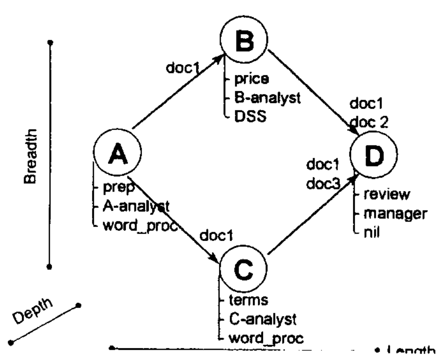

Figure 5 Alternative Process Representation

Further, one can use configuration measurements such as these to formulate predictive hypotheses pertaining to relative performance of alternative processes. For instance, given the activities represented by nodes B and C in the figures denote the same process tasks in two alternative enterprise designs, one could hypothesize a corresponding cycle-time difference between the alternative processes.

Hypothesis 1. Where the configurations of two alternative process designs differ only in terms of measured length, the process design corresponding to the shorter length measurement is expected to exhibit performance with proportionately lower cycle time.

This hypothesis suggests, *ceteris paribus*, that process length—a configuration or input measure—is directly related to cycle time—a performance or output measure. As such, a designer could use this hypothetical relation to predict the relative performance of alternative enterprise process designs. Further, in a deductive manner, the engineer could work backward—from cycle time performance requirements—to determine appropriate parameter values for process length. This represents a design capability not available to the enterprise designer today. Of course, the validity and level of this hypothetical relation between process length and cycle time requires empirical testing and estimation.

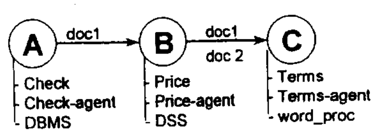

Figure 6 Modified Process Design

Similar predictive hypotheses can be formulated to relate other configuration and performance measures. For instance, say the process design delineated in Figure 4 is modified to omit the review activity represented by Node D. This latter process, presented in Figure 6, would then have process size of three instead of four. Given the activities represented by nodes A, B and C in the figures denote the same process tasks in two alternative enterprise designs, one could hypothesize a corresponding cost difference between the alternative processes.

Hypothesis 2. Where the configurations of two alternative process designs differ only in terms of measured size, the process design corresponding to the smaller size measurement is expected to exhibit performance with proportionately lower cost.

This hypothesis suggests, *ceteris paribus*, that process size—a configuration or input measure—is directly related to cost—a performance or output measure. In essence, both process designs would involve the same three activities—represented by Nodes A, B and C—and incur the same cost for these three. However, the process design that omits the activity represented by Node D would not incur the corresponding cost, and hence it would constitute a lower-cost enterprise process alternative.

To generalize, provided an enterprise process can be represented using the kinds of attributed directed graphs presented above, this graph-based measurement scheme can be employed to quantify various dimensions associated with process configuration, dimensions that can be used for comparison, contrast and prediction. And the kinds of measures that can be defined for and obtained from enterprise processes are limited only by one's ability to represent a particular enterprise process using attributed, graph-based constructs. Thus, the approach appears to be generalizable. This represents the first step toward using configuration measurement and analysis to support enterprise process design[2].

MEASUREMENT THEORY AND APPLICATION

In this section, we draw from Measurement Theory to discern key properties of the graph-based measures developed above. These properties are important to understand the strengths and limitations of graph-based measures, particularly in terms of the type of scale supported by our enterprise process measures and the corresponding inferential power of measurements obtained.

Like Graph Theory, Measurement Theory also has its basis in the mathematics of Set Theory and Relation Theory. This makes it fundamentally compatible with the graph-based constructs developed in the preceding section. The purpose of drawing from Measurement Theory is to provide a rigorous basis for

[2] Further, we should note the small set of measures developed above is not intended to be complete at this point in our investigation. Rather, the idea is to develop a few, fundamental measures and examine their properties and use for enterprise process configuration and design. Nonetheless, the ability of a few, fundamental measures to support the development of a robust analytical capability is well known. In the physical sciences, for example, nearly all measurement in physics, engineering and like disciplines can be traced to a set of just *six*, fundamental measures—charge, temperature, mass, length, time and angle (Krantz et al. 1971).

evaluating the inferential power and meaningfulness of graph-based enterprise process measures. And for use in enterprise process design, we are particularly interested in measures able to support ratio scales. Unlike the powerful ratio scales that are predominant in the physical sciences, social science researchers have long struggled with the inferential power and meaningfulness of measures obtained through their instruments [23].

Measurement Theory Fundamentals

Measurement Theory has been actively developed and studied for several decades and now represents textbook knowledge. The background discussion in this section draws principally from work by [15] and [23] who explicitly address its application in the social sciences. *Measurement* is defined in [15 , p. 9)]as, "... the construction of homomorphisms (scales) from empirical relation structures of interest into certain numerical relation structures that are useful." A later definition follows [23, p. 50]: "... assigning numbers that correspond to or represent or 'preserve' certain observed relations." Notice both definitions are procedural; that is, they describe a procedure for obtaining measurements.

The development of a measurement system involves two primary problems: 1) the representation problem, and 2) the uniqueness problem. The representation problem can be defined as follows. Given a particular numerical relation system (NRS) W, find the conditions of the corresponding empirical relation system (ERS) U that are necessary and sufficient for the existence of a homomorphism F from U to W. A triple (U, W, F) defines a *scale*, the inferential power of which is important to us. This set of (ERS) conditions provides a basis for the development of axioms for the representation, which in turn have been used to develop and prove representation theorems to succinctly state their sufficiency.

The uniqueness problem addresses the question, how unique is a particular homomorphism? This question has three important parts: 1) What is the nature of the scale? 2) What transformations can be performed without corrupting the scale? 3) What inferences can be made from measurements obtained through the scale? The key to answering these questions lies in the manner of scale construction. In this paper, we employ the method of standard sequences.

Standard sequences are used to establish a standard, against which all measurements can be compared, and to calibrate the ensuing scale for measurement of objects of interest in the real world. The method of standard sequences has been proven to produce scales with three desirable properties [15, p. 4].

Property 1. The resulting scale represents a satisfactory ordinal measure.

Property 2. The resulting scale is additive with respect to concatenation and aggregation.

Property 3. Ratios are unique, regardless of the choice of unit to serve as a standard.

Constructing measures in this manner is referred to as *extensive measurement.* And if we can successfully use extensive measurement to construct the graph-based measures proposed above for the enterprise process configuration, by Property 3, we can infer such measures support ratio scales.

Extensive Measurement Scale Construction

We first examine the measure *process length* using extensive measurement. This represents exactly the same approach used for the physical measure *length*, which is constructed from a sequence of standard distances (e.g., foot, meter; see [15] for details) concatenated in an end-to-end fashion (e.g., like laying rulers end to end). Recall our graph-theoretic discussion of *path* above, from which we define the corresponding construct *length* (see Definition 2). Using this definition and the associated terms, the vertex (i.e., node) represents a standard unit that can be readily observed in a graph. And by concatenating such standard units together through edges, we can construct a path that conforms to the measurement-theoretic definition of a standard sequence.

Say we measure a graph-based representation for some simple[3] process ("Process A") and obtain a measured value of four for process length. And, for sake of simplicity, say the process flow is sequential as delineated at the top of Figure 7. From the figure, one can observe Process A appears to be longer than some other simple process ("Process C"), the latter of which is delineated at the bottom of Figure 7. With this, we can observe the empirical relation "longer than" between these process representations. When we obtain a length measurement for Process C, we note the measured value of three is less than the length of

[3] We use relatively simple examples to illustrate the approach. But the approach is in no way limited to such simple processes. Indeed, the value of this approach lies in its ability to scale for representation and measurement of large, complex processes that are not so easily understood and designed.

four obtained from the Process A representation. Therefore, this numerical relation (4 > 3) preserves the empirical relation (i.e., Process A is longer than Process C).

Further, we note each node in the graph represents one standard unit, and the representations for Processes A and C are both comprised of these same standard units. From this, one can observe the Process A representation is comprised of exactly four of these standard units concatenated in an end-to-end fashion, whereas the representation for Process C is comprised of exactly three of these same, concatenated units. By using these, same standard units, concatenated in a comparable (e.g., end-to-end) manner, we have adhered to the procedure above for scale construction and hence shown that both process representations are constructed from standard sequences. Therefore, they accrue the properties of extensive measurement, including support of a ratio scale. Thus, not only can we infer Process A is longer than Process C (i.e., an ordinal relation), we can also infer the length of Process A is 4/3 the length of Process C. This latter inference represents the kind obtainable only through a ratio scale.

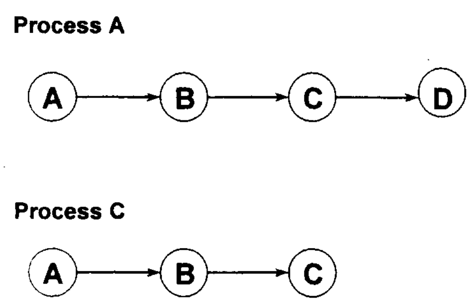

Figure 7 Processes as Standard Sequences

To generalize, we can apply the extensive-measurement procedure to the other graph-based measures defined in Table 1 as well. For instance, returning to the two directed graphs presented in Figure 7, say we measure a graph-based representation for Process A and obtain a measured value of four for process size. When we obtain a size measurement for Process C, we note the measured value of three is less than the process size of four obtained from the Process A representation. Therefore, this numerical relation (4 > 3) preserves the empirical relation (i.e., Process A has more than Process C).

Following the same logic applied above, we note each node in the graph represents one standard unit. By using these, same standard units, aggregated in a comparable (e.g., collective) manner, we have adhered to the procedure above for scale construction and hence shown that both process representations are constructed from standard sequences and support a ratio scale.

As above, we note this is exactly the kind of analysis used to determine the measure *mass*, used extensively in the physical sciences, which supports a ratio scale. And again, this extensive-measurement approach can be applied to any of the graph-based measures defined in Table 1, in addition to other measures based on like graph-theoretic concepts (e.g., node, edge, path, cycle) and measurement operators (e.g., concatenation, aggregation). This makes the graph-based measurement approach quite generalizable.

Limitations

This approach is not without limitations. In a strict sense, one can argue the nodes used to construct standard sequences above are not sufficiently standard across process designs. For instance, this argument implies Nodes A, B and C (depicted in Process A and C of Figure 7) must represent the *same activities* of any two alternative processes. This argument focuses on the standard unit (i.e., node) used to construct the corresponding standard sequence (i.e., path) and suggests the node may not represent a suitable standard for extensive measurement.

In the physical sciences, by contrast, standardization is guaranteed by use of an international standard length (e.g., meter) that is precisely defined. For instance, the length of a standard meter is defined as follows [24].

The length is exactly 1,650,763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the Krypton-86 atom.

It is unlikely our representation of enterprise process configuration can be defined with a comparable level of precision. And it is unclear what process construct in the physical world could be used to establish such a precise standard unit to represent the process activity. Alternatively, it is not clear that such a precise standard is necessary, or even desirable, in the domain of enterprise process design. Theoretical and empirical work to address this question represents a noteworthy topic for future research.

Other limitations can also be identified. First, not all important elements associated with an enterprise process lend themselves to graph-based representation. For instance, management culture is stressed as an important determinant of enterprise performance. Hence, one would like to represent this concept as part of enterprise process configuration. But it is unclear how such a concept can be operationalized in terms of graph-theoretic constructs (e.g., nodes, edges, paths).

Second, not all process configuration measurements lend themselves to performance prediction. For instance, the configuration measures *process length* and *process size* offer potential as determinants of the corresponding performance indicators *cycle time* and *cost*, respectively. But it is unclear how other configuration measures such as *reviews* can be used to predict performance factors.

Third, many relations between enterprise process configuration and performance are likely to be complex and difficult to determine. For instance, a relation between the configuration measure *reviews* may be related to the performance indicator *quality*. But one would not expect more reviews (e.g., by increasing the number of inspections) to necessarily correspond with greater quality. And interactions between alternative performance measures—such as cycle time, cost and quality—may be predicted only through complex combinations and levels of various configuration measures (e.g., process parallelism, review fraction).

CONCLUSIONS AND IMPLICATIONS

The enterprise process has become a central unit of analysis in management. But a dearth of theory and methods to predict process performance is available to the enterprise manager. Building on seminal work for process description and comparison, we draw from the Enterprise Process Model for graph-based configuration constructs and measures developed specifically for the enterprise process. Then employing Graph Theory and Measurement Theory, we integrate this work and demonstrate useful analytical properties associated with the kinds of measures proposed. In particular, using extensive measurement based on standard sequences, we show the graph-based measures *process length* and *process size* support ratio scales. And we generalize this discussion to indicate ratio scales can be supported by any of the graph-based measurement constructs employed in our scheme to represent the enterprise process configuration.

This represents a new result, which extends the prior research on enterprise process design and makes a contribution to our understanding in management science.

Further, with parallels to the predictive capability enjoyed by engineers who design physical artifacts, we indicate how enterprise process configuration measures can be used to hypothesize relations with respect to enterprise performance. Although such hypothetical, configuration-performance relations remain to be empirically verified and quantified, the graph-based measurement method developed through the present research provides theoretically-sound, operationalized constructs to support such empirical testing and estimation. Also, with parallels to the deductive manner in which engineers who design physical artifacts are able to work backward—from performance requirements—on designs, we indicate how enterprise process configuration measures can be used to determine configuration parameters required for designs to meet performance goals. These represent new capabilities not previously available to the enterprise manager and another contribution of the present research.

Alternatively, we also indicate this measurement-based design approach has limitations. Depending upon how strictly one interprets the construct *standard* used in constructing standard sequences, an argument can be made that the kinds of graph-based configuration measures discussed in this paper are applicable only to comparison of the same process activities; that is, such measurements cannot be used to compare configurations of different processes.

Other limitations are identified as well. But despite these limitations—and the many others yet to be identified—the measurement capability provided through our graph-based approach enables enterprise process design to be approached in a novel manner, with parallels to the methods employed by engineers who design physical artifacts. Clearly, this represents only a beginning step toward enterprise process engineering. But through configuration measurement and analysis, we hope to enable enterprise process design to be approached as much as an engineering problem as a managerial one. And we hope the work described in this paper stimulates future research along these lines.

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